Research, Production and Application of V-N Microalloyed High Strength Reinforcing Bar for Building in China

Caifu YANG
Deputy Director, Structural Materials Department
Central Iron & Steel Research Institute
No.76, XueYuanNanLu
Beijing 100081, P.R.China

Robert J Glodowski
Director, Technical Services
Stratcor Inc.
4955 Steubenville Pike
Pittsburgh, PA 15205 USA

ABSTRACT: *The paper reviewed the research, production and application of V-N microalloyed high strength concrete reinforcing bar (rebar) in China. Enhanced-nitrogen in V-containing rebar promotes precipitation of fine V(C,N) particles, and improves markedly precipitation strengthening effectiveness of vanadium. Therefore, V addition in V-N microalloyed rebar can be reduced by 40% compared with the same strength level of V-containing rebar.*

KEYWORDS: *high strength reinforcing bars, V-N microalloyed, precipitation strengthening*

1. Introduction

Reinforcing bars, as the biggest steel products in China, take about one-fourth of the total steel production. Recently, the production and consumption of hot-rolled rebars in China increased dramatically as fast development of the national building industry. As shown in Fig.1, the total annual rebar production in 2004 approaches to 71 million tons, nearly five times as much as that in 1995.

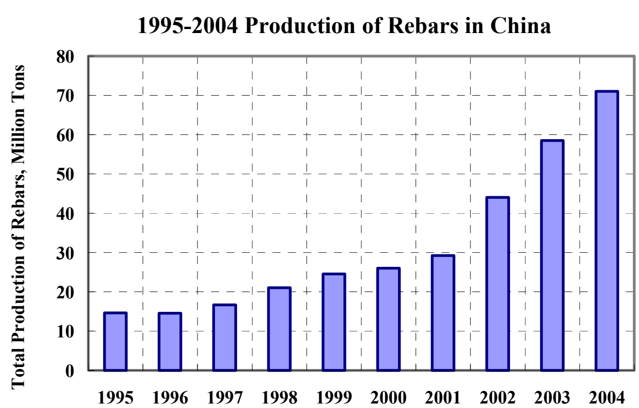


Fig.1 Rebars Production in China in past decade

However, the rebar products mix has yet no obvious change, and was still dominated by grade 2 rebar. At present, near 90 percent of the rebar production is grade 2 rebar with yield strength of 335 MPa in Chinese market. Whereas, in Western developed countries, the rebar for building had upgraded to grade 3 rebar with yield strength of 400MPa or above. For example, grade 4 rebar with yield strength of 500 MPa has been widely used in Germany [1]. A large amount of application experiences indicated that the rebar consumption can be saved by 14% if the strength of rebar upgrade from grade 2 to grade 3. Therefore, there will be a great social and economic benefits to promote the substitution of grade 3 rebar for grade 2 rebar in China.

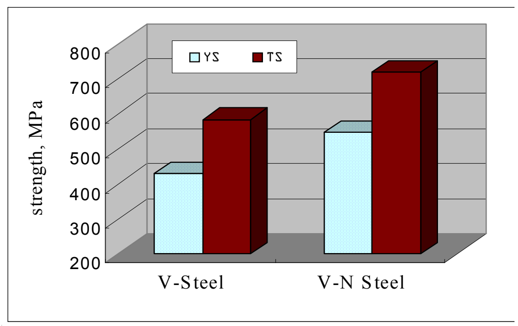
This paper reviews the research, production and application of high-strength rebar with V-N microalloyed process in China.

2. Experimental research of V-N microalloyed high-strength rebars

Microalloying process is mainly adopted to develop high-strength weldable rebar all over the world[1-3]. For rebar production, high rolled rate and high finish rolled temperature make it be quite suitable to apply vanadium microalloy technique in rebar alloy design[2]. The latest rebar standard issued in China also recommends to use vanadium microalloy to produce grade 3 rebar with the min yield strength of 400MPa[3]. However, V addition will raise markedly the production cost of rebar. It is known that microalloying element takes effects by the precipitations of its carbide/nitride, and microalloyed nitrides had obviously better strengthening effectiveness than carbide as the nitride particles are more stable and finer. A lot of research results indicated that nitrogen is a cost-effective alloy element in vanadium microalloyed steels, and the strengthening effectiveness of nitrogen in vanadium bearing steel could be up to about 6 MPa strength increment for per 10ppm nitrogen. The successful application of V-N microalloyed technology in high-strength rebar developed a cost-effective way for grade 3 rebar production in China [6-9].

2.1 Effect of Nitrogen

Figure 2 show the effect of Nitrogen on the strength of vanadium-bearing rebar steels. With the same V-content, the strength of V-N steel has much higher than that of V steel. It can be seen that, with the enhancement of 100ppm Nitrogen, the yield strength and tensile strength of V-N steel increase by 117.5 MPa and 135 MPa respectively compared to V steel. The results show that Nitrogen improved the strengthening effectiveness of vanadium in steel markedly, and it means that nitrogen is a very effective strengthening element for Vanadium-bearing rebar.



Steel	0.11%V-85ppm[N]	0.12%V-180ppm[N]
YS	442.5 MPa	560 MPa
TS	585 MPa	720 MPa

Fig. 2 the strength of V-steel and V-N steel

2.2 V distribution and precipitation in rebar

Vanadium distribution in V steel and V-N steel is shown in figure 3. In V-steel, V mainly exists as solid solution accounting for 56.3% of the total V content, while only 35.5% V precipitates in form of V(C, N). The results reveal that most microalloying element in V-steel does not work for precipitation strengthening and it is a waste for vanadium. On the contrary, in V-N steel 70% V forms V(C, N) precipitates and only 20% dissolves in matrix. Hence, Nitrogen addition alters V distribution in steel, and promotes the precipitation of vanadium dissolved in matrix, thus improves the precipitation strengthening of vanadium.

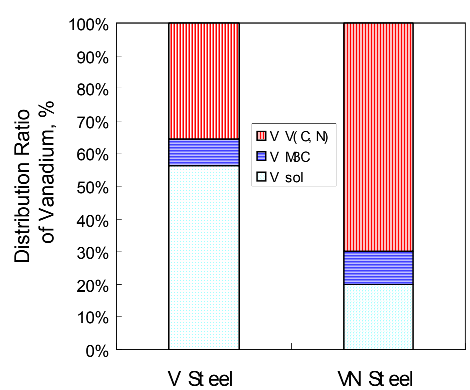


Fig. 3 Vanadium distribution in V-steel and V-N steel

Table 1 lists the results of V(C, N) precipitates volume in V-steel and V-N steel. It can be seen that the amount of V(C, N) precipitates in V-N steel is over twice as much as that in V-steel. It is clear that the enhanced nitrogen in V-N steel promoted V precipitation markedly and it should be one of main reasons for the strength improvement in V-N steel.

Table1 volume of V(C,N) precipitates in V-steel and V-N steel, wt%

Steel Grade	compositions	Volume of V(C,N) precipitation phase
V Steel	0.11%V-85ppm[N]	0.0498
V-N Steel	0.12%V-180ppm[N]	0.1062

Figure 4 shows the size distribution of V(C, N) precipitates. The fraction of fine particles with size of less than 10nm in V-steel is just only 21.1%, while the fraction is up to 32.2% in V-N steel. As the result shows, N-addition in steel not only promotes precipitation of V(C, N) but reduces the average size of V(C, N) particles, and greatly increases the fraction of fine particle precipitates, which also makes the great contributions to the strength increase in V-N steel.

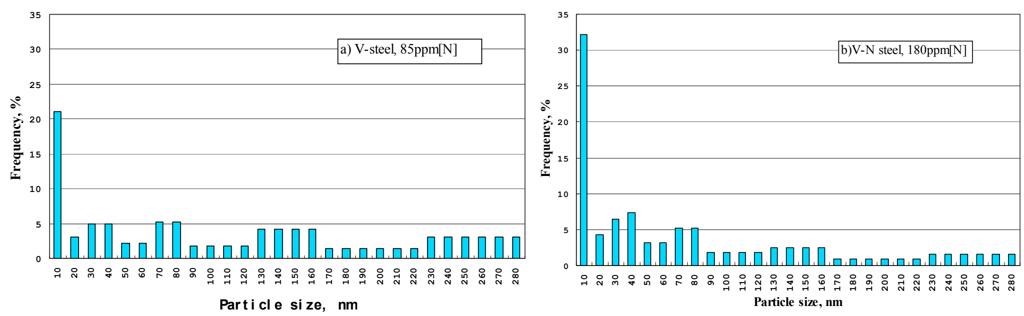


Fig.4 Particle size distribution of V(C,N) precipitates in V-steel (a) and V-N steel (b)

2.3 Strengthening mechanism of V-N rebar

Based on copious research results, strength relation of microalloyed steels can be expressed by: [10]

$$\sigma_S = 85.7 + 37[Mn] + 83[Si] + 17.4 \times D^{-1/2} + \sigma_{PR}$$

where the second and third items denote Mn and Si solid strengthening and $17.4 \times D^{-1/2}$ denotes grain refining strengthening and σ_{PR} denotes precipitation strengthening.

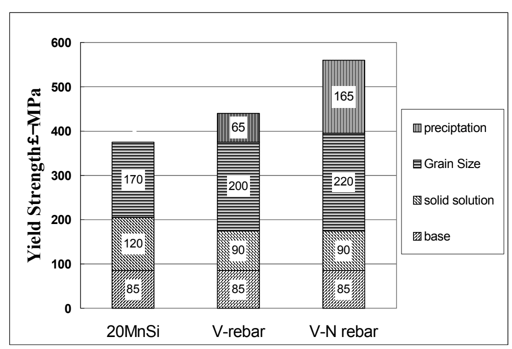


Fig.5 Strengthening Mechanism of 20MnSi, V rebars and V-N rebars Steels

According to the experimental results of ferrite grain size and yield strength for the tested steels, the contribution of each strengthening mechanism to the yield strength of V steel and V-N steel was shown in figure 5. It can be seen that the strength difference between V steel and V-N steel mainly results from different contribution of precipitation strengthening and grain refinement strengthening. The contribution of precipitation strengthening (σ_{PR}) and grain refinement strengthening on yield strength for V-N steel is over 70%.

3. Production and properties of V-N microalloyed rebar

3.1 Optimization in chemistry for V-N rebar

Based on the research works in lab, the strengthening capability of V and V-N microalloying in high strength rebar produced by converter + continuous casting process were compared by the mill scale trials. The mill trials results were shown in figure 6. It can be seen that V-N rebar with 0.03-0.09%V and V rebar with 0.06-0.14%V reached almost at the same strength level. The mill trial's results also indicated that the strengthening capability of vanadium in V-N steel is much stronger than one in V-steel. Thus, for a given strength requirement, the V content in V-N microalloyed steel can be saved markedly compared with V steel.

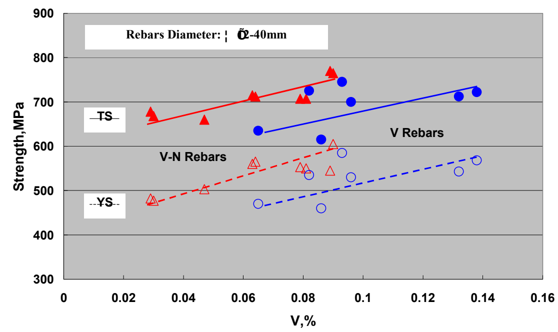


Fig.6 effect of V on the strength for the mill trials scale rebars

The regression results on the strength data of the mill trial rebar indicated that the yield strength of V steel and V-N steel can be expressed as following formula:

V-Steel□ σs□$\sigma s_{(20MnSi)}$□$1056\times[V\%]$

V-N Steel□ σs□$\sigma s_{(20MnSi)}$□$1994\times[V\%]$

It can be seen clearly from regression results that the strengthening effect of vanadium in V-N rebars is almost double compared with that in V rebar.

The optimized compositions for grade 3 rebar with V and V-N microalloyed process were given in Table 2. The vanadium content in V-N microalloyed grade 3 rebars with min yield strength of 400MPa can be reduced to 0.02-0.04%, and is only half level in V-Fe microalloyed grade 3 rebar.

Table 2 the chemistry composition of grade 3 rebar (wt%)

Steel	Rebar size	C	Si	Mn	P, S	V	N	additive
V Steel	≤16 mm	0.18-0.24	0.45-0.60	1.25-1.45	0.035	0.05-0.07	Res.	V-Fe
	>16-40 mm	0.18-0.24	0.45-0.60	1.25-1.45	0.035	0.07-0.09	Res.	
V-N Steel	≤16 mm	0.18-0.24	0.45-0.60	1.25-1.45	0.035	0.02-0.03	Res.+20-30ppm	V-N
	>16-40 mm	0.18-0.24	0.45-0.60	1.25-1.45	0.035	0.03-0.04	Res.+30-40ppm	

3.2 Process consideration

It is ease to control in the production process for V-N microalloyed grade 3 rebar. In actual, there is no essentially difference in the production process for V and V-N microalloyed grade 3 rebars compared with that of 20MnSi grade 2 rebar. For achieving the maximum precipitation strengthening effect, it is necessary to make sure the full dissolution of vanadium carbonitrides during soaking. To V containing steel, it is not difficult to dissolve fully V(C,N) precipitates due to it's high solubility, so the billet's reheating temperature is not too high, and normally it was reheated to 1150-1200□.The accelerating cooling process was used in general after finish rolling for refining the final ferrite grain size.

Steady recovery of vanadium and nitrogen is very important to control the fluctuation of rebar's properties. The statistic results from a number of industrial production data showed that the scatter of vanadium content is very narrow (±0.002%) in V-N grade 3 rebar microalloyed by Nitrovan alloy, an additive of vanadium and nitrogen. In contrast, for V rebar steel added V-Fe alloy, it can be seen that there is larger scatter in vanadium content (±0.01%).

Nitrogen content in V-N steels will depend on V addition. The mill trial results shown that for optimized industrial operations, 10 ppm nitrogen will be added for each 0.01% V added as Nitrovan 12, and for Nitrovan 16, about 13 ppm nitrogen is added for each 0.01% V.

3.3 Properties of V-N Rebar

3.3.1 Tensile properties

The mechanical properties of V-N microalloyed grade 3 rebar were given in table 3 and table 4, and the effect of rebar size on the mechanical properties was shown in Fig.7. It can be clearly seen that the mechanical properties of V-N microalloyed rebar are quite stable. The yield strength fluctuates between 425MPa and 500MPa with a fluctuation scope as 75 MPa whilst the tensile strength fluctuates between 575MPa and 660 MPa with a fluctuation scope as 85 MPa, and elongation is between 19% and 32%. All kinds of rebar meet one-class anti-quake requirement that tensile/yield strength ratio is higher than 1.25. Totally, the determined chemical compositions of V-N microalloyed rebar are suitable.

The result shows that average σ_s fluctuates within 17 MPa and average σ_b within 19 MPa, indicating that V-N rebar have excellent mechanical performance stability and are hardly affected their size.

Table 3 Mechanical Properties of V-N Microalloyed Hot-rolled Rebar

Rebar Size mm	σ_s, MPa		σ_b, MPa		δ_5, %	
	Scope	Average	Scope	Average	Scope	Average
10	480-500	493	650-675	665	26-33	30
12	460-490	478	600-640	631	29-32	30
14	450-500	482	590-640	625	26-33	28
16	430-485	463	585-620	616	26-29	27
20	465-490	478	605-640	622	22-29	26
22	445-485	468	590-645	621	24-27	25
25	450-500	474	590-660	623	19-31	26
28	425-475	447	575-640	608	22-29	25
32	455-480	467	605-625	614	20-23	22
36	440-500	458	595-610	602	22-24	23
40	445-465	455	590-625	608	18-25	22

Tab.4 Mechanical Properties of V-N Microalloyed Coiling Rebar

Size mm	Chemical Composition□%				σ_s, MPa	σ_b, MPa	δ_5, %
	C	Si	Mn	V			
Φ6	0.23	0.57	1.41	0.030	475~530	645~705	22~36
Φ6	0.23	0.57	1.41	0.030	495~520	680~715	21~28
Φ6	0.21	0.54	1.36	0.023	460~475	680~695	25~30
Φ8	0.21	0.55	1.36	0.024	460~480	665~670	26~30

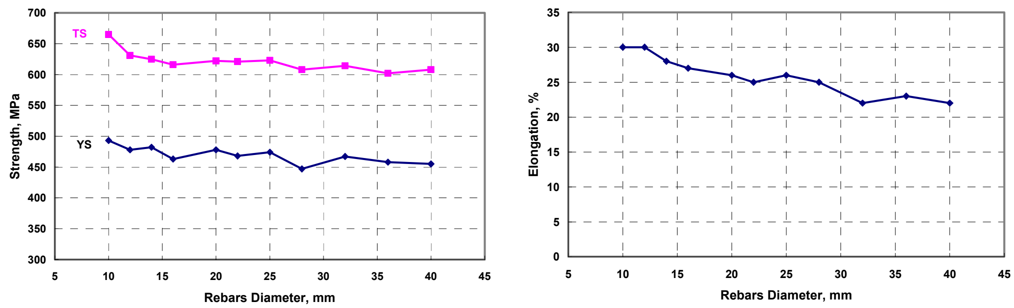


Fig.7 Effect of Rebar Size on the Strength and the Elongation of V-N Rebar

3.3.2 Strain aging

The strain-aging index, that is the increase in flow stress after aging a pre-strained sample, was used to evaluate the strain aging of V-N rebar. By the requirement of the National Standard on strain aging test, the pre-strain was selected as 5%, and the aging was at 250°C for 1 hour.

Fig.8 shows the results of a strain aging evaluation of V-N rebar and 20MnSi rebar. The results show that there is no strain aging in V-N rebar, and the 20MnSi steels had a significant strain aging response.

Tab.5 Aging Effect on the Properties of V-N Rebar

Steel	Non-aging			After aging		
	σ_s, MPa	σ_b, MPa	δ_5, %	σ_s, MPa	σ_b, MPa	δ_5, %
V-N	460	640	27	470	655	25
20MnSi	380	575	30	425	615	24.5

3.3.3 Weldability

Four typical welding process for rebar joint, including flash butt welding, gas-pressure welding, shield metal arc welding (SMAW) and slag pressure welding etc., were used to evaluate the weldability of V-N microalloyed rebar. The testing results in table 6 show that V-N microalloyed hot-rolled ribbed rebar has excellent weldability and are suitable for different welding process mentioned above.

Table 6 the Mechanical Properties of Welding Joints

Welding Process	Size mm	σ_s MPa	σ_b MPa	Position of Fracture	Cold Bending, 90° d=5a	d=6a
Flash butt welding	Φ25	475,455,455	655,640,640	Base	Pass	
	Φ32	440,430,420	590,610,590	Base		Pass
	Φ36	430,430,435	610,605,615	Base		Pass
Gas-pressure welding	Φ25	450,455,435	630,635,625	Base	Pass	
	Φ32	415,420,420	590,595,595	Base		Pass
	Φ36	440,425,435	615,600,615	Base		Pass
Manual arc welding	Φ25	470,470,470	650,650,650	Base	Pass	
Slag pressure welding	Φ25		650,635,650	Base	Pass	
	Φ32		615,615,610	Base		Pass

3.3.4 Low-cycle fatigue

Figure 8 shows the curve of fatigue life of V-N and 20SiMn rebar. The experimental results indicated that the fatigue property of V-N rebar is better a little than that of 20SiMn rebar.

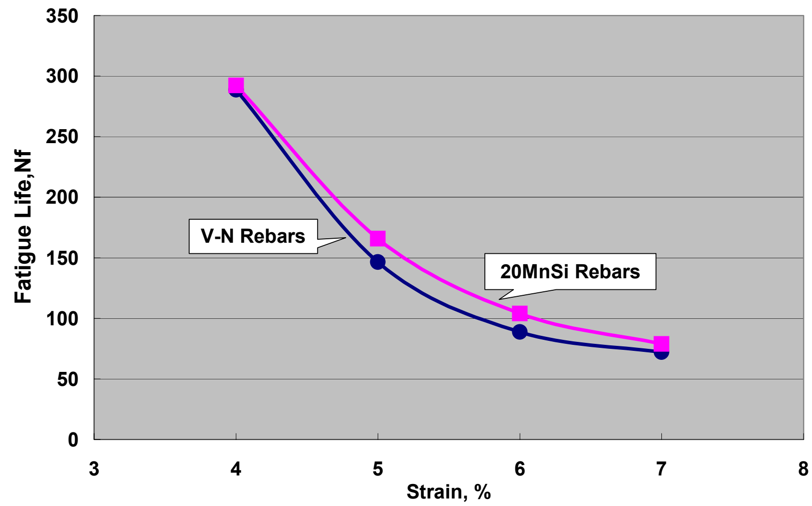


Fig.8 Curve of Fatigue Life of V-N and 20MnSi Rebar

4. Production and application of high-strength rebar in China

Fig.9 shows the variation of production and proportion of high-strength grade 3 rebar in China since 2000. It can be seen that there was a fast growth in production of grade 3 rebar in last five years. The total production for grade 3 rebar increased to 8.5 million tons in 2004 from 260 thousand tons in 2000. However, the proportion of grade 3 rebar in total rebar production was still very low and only 12% till to 2004. It means that grade 2 rebar still took the dominated position in Chinese building market.

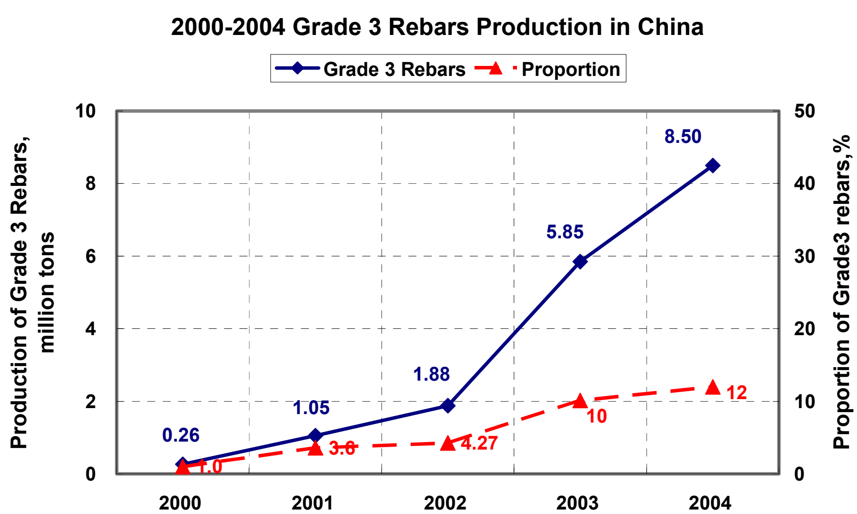


Fig.9 Production and Proportion of Grade 3 Rebar in China

5. Summary

(1) V-N multi-microalloyed process promotes the precipitation of V(CN) in steel, and contributes to stronger precipitation strengthening effectiveness of V(CN) particles. Thus V addition can be saved for given strength level. Therefore, V-N microalloying technology is a cost-effective way to develop high strength grade 3 rebar.

(2) V content in grade 3 rebar can be reduced to 0.02-0.04% by V-N microalloying, and V savings can be over 40% compared with V-Fe microalloyed rebar.
(3) Stable mechanical properties can be obtained in V-N microalloyed grade 3 rebar. The industrial production results indicated that the fluctuation of yield strength and tensile strength for grade 3 rebar can be controlled within 75MPa and 85MPa, which ensured the rebar to satisfy first class seismic requirements.
(4) V-N microalloyed grade 3 rebar show a satisfactory service performance. Along with the high ductility, it also exhibits a high strength, low susceptibility of strain aging, good weldability and seismic characteristics.
(5) The fast growth in production of grade 3 rebar had been seen in China in past five years, however the proportion of grade 3 rebar in total rebar production is still very low and only nearly 10%. So producers and users for grade 3 rebar still need to pay long-term jointed efforts to promote its application.

Reference

1. D.Russwurm and P. Wille. "High Strength Weldable Reinforcing Bars". Microalloying'95, Pittsburgh, PA, ISS, 1995
2. M Korchynsky. "Overview". Proc. 8th Process Tech. Conf., Iron and Steel Society, 1988:79□87.
3. National Standard GB1499-1998, "Hot Rolled Ribbed Steel Bars for the Reinforcement of Concrete", 1998.10. (in Chinese)
4. S.Zajac, R.Lagneborg, T.Siwechi. "The Role of Nitrogen in Microalloyed Steels". Proc. Int. conf. Microalloying '95, Pittsburgh, PA, ISS, 1995:321□340.
5. S.Zajac, T.Siwechi, *etal*. 'Strengthening Mechanism in Vanadium Microalloyed Steel intended for Long Products', ISIJ International, vol.38, No.10, 1998:1130-1139
6. Y.-Q. Zhang, C.-F. Yang, S.-P. Liu, "Study on Economical Grade 3 Rebar for Building", Iron & Steel, vol.35, No.1, 2000, p.43-46 (in Chinese)
7. C.-F. Yang, Y.-Q. Zhang, S.-P. Liu, "Precipitation Behavior of Vanadium in V-N Microalloyed rebar Steels", HSLA Steels'2000 (eds. Liu Guoquan,etal, Metallurgical Industry Press, 2000,10), 4th International Conf. on HSLA Steels, Oct.30-Nov.2, Xi'an China, p152-157
8. Y.-Q. Zhang, C.-F. Yang, S.-P. Liu, "strengthening mechanism of V-N microalloyed rebar", Iron & Steel, vol.36, No. 5, 2001, p.55-57 (in Chinese)
9. H.-Z. Ji, C.-F. Yang, Y.-Q. Zhang, "effect of nitrogen on the strengthening effectiveness of 20SiMnV Steel rebar", Special Steel, Vol.21,No.5, 2000,p.20-23 (in Chinese)
10. Q.-L. Yong, M.-T. Ma, B.-R. Wu. "Microalloyed Steel—Physical and Mechanical Metallurgy", Machinery Industry Press, Beijing, 1989:57. (Chinese)
11. National Standard GB5001-2002, "Design Code of Concrete Building", 2002.10. (in Chinese)